

Lighten up!



Honda's 2009 Insight hybrid uses AHSS and HSS for the body structure, rather than a high proportion of light metals, in an effort to balance cost, safety, and weight. While the all-new Insight could be lighter, Honda is banking on hybrid propulsion, aerodynamics, and interactive controls to help encourage more fuel-saving driver behavior, rather than extreme mass reduction.

Automakers and suppliers accelerate their efforts to reduce vehicle weight by engineering them for greater use of lighter, stronger materials.

by *Lindsay Brooke and Harry Evans*

Weight reduction is again a priority across the industry, as strict new regulations push for greater vehicle efficiency/ CO_2 reduction in the U.S. and Europe. From the smallest fasteners to entire vehicle architectures, engineers are wringing excess ounces out of new components and systems, while looking for new ways to lighten up existing designs.

The benefits of lightweighting correlate directly to greater fuel economy as well as to improved vehicle dynamics. Studies have shown that every 10% reduction in vehicle weight can yield 5 to 8% greater fuel efficiency. Dropping 150 lb (68 kg) on average gives an extra mile of driving range per gallon of fuel consumed. In terms of its effect on carbon emissions, reducing vehicle weight by 220 lb (100 kg) brings a CO_2 reduction of up to 12.5 g/km.

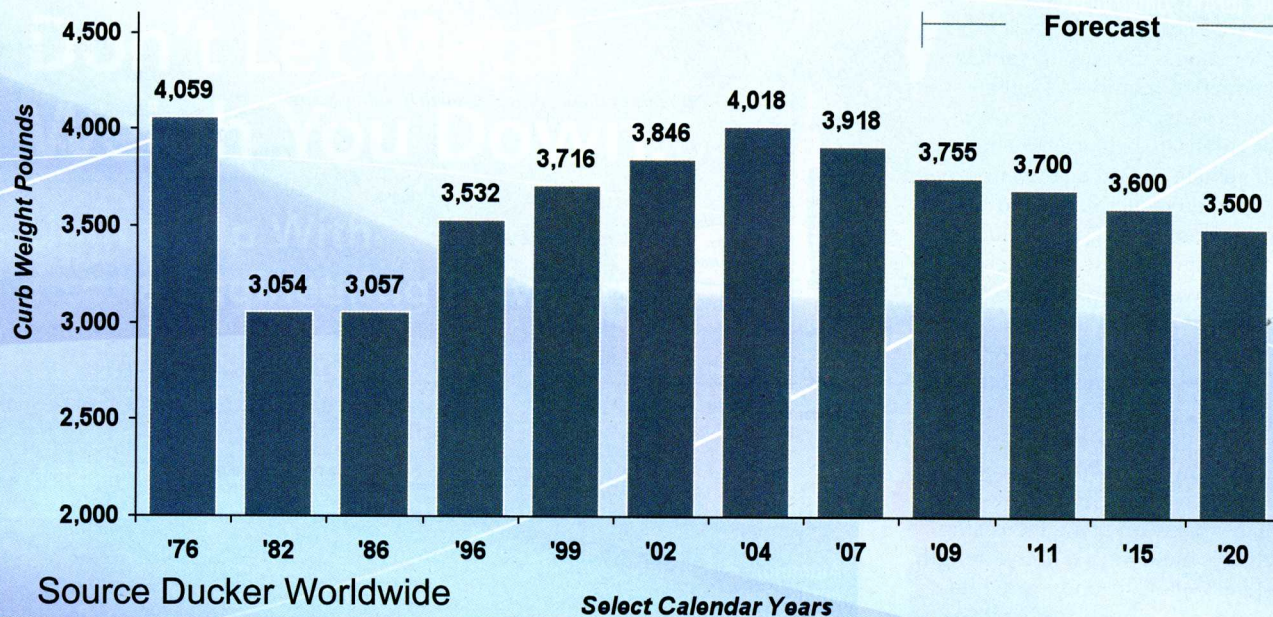
Automakers have made mass reduction part of their vehicle development strategies going forward, while ensuring no sacrifices in safety or durability. **Nissan**, for example, has pledged to slash average vehicle curb weight by 15% through 2015. **Ford**, as part of its corporate goal to boost fleet fuel economy 40% by 2020, aims to reduce vehicle weight by 240 to 750 lb (109 to 340 kg),

depending on the model.

A daunting task for every OEM will be dealing with "mass creep"—the tendency to make each new-generation model heavier than its predecessor. Mass creep is caused by adding new features, safety equipment, and emissions-control content. Consumers also expect new models to be larger and more commodious than the ones they replace.

"Offsetting extra pounds added by new features definitely is a challenge," noted Matt O'Leary, Chief Engineer on Ford's 2009 F-150. He said it takes great attention to detail to achieve mass parity between vehicle generations. Genuine mass reductions are a tougher task, one that O'Leary's team accomplished. The F-150 base model, for example, arrived approximately 100 lb (45 kg) lighter than the equivalent '08 model even though it is larger and better equipped.

Last year's all-new **Mercedes-Benz** C-class sedan was that company's first new model that was not heavier than its predecessor, despite growing in size and feature content. Ditto for the current **Mazda2**, which last year came in 220 lb (100 kg) lighter than the previous model.



Ducker Worldwide's latest North American vehicle curb weight forecast through 2020 shows more than 250 lb (113 kg) will have to be shed per unit within the next decade. The 3500-lb (1590-kg) curb weight in 2020 assumes 20% full frame vehicles and 80% unibody vehicles, vs. 42% full frame in 2004, 34% full frame in 2007, and 25% in 2009.

Today's mass-reduction efforts likely will not be as swift or dramatic as those that transformed the U.S. passenger-car fleet 30 years ago. Back then, the domestic makers launched bold vehicle-downsizing programs to meet the new CAFE regulations. Their massive shift from body-on-frame to unibody structures, from V8 engines to V6s, and from rear-wheel drive to front drive, was combined with smaller platforms—wheelbases were shortened by an average 7 in (178 mm).

The net result was an average 1000-lb (454-kg) reduction in U.S. passenger vehicle curb weight, with an equally sharp jump in fuel efficiency. (Critics claimed it also compromised occupant safety.) Suppliers were incentivized to aid the cause: In the early 1980s, **General Motors** paid back its suppliers \$1 for every pound trimmed from their products.

A recent shift in the North American fleet mix is again precipitating a drop in average curb weights. It is due to the collapse of the full-size SUV segment, the rise in unibody crossovers, and a falloff in non-commercial pickup sales, explained Dick Schultz, Project Consultant with **Ducker Worldwide**, which analyzes automotive materials

trends and technologies.

"In the past five years, we've lost a whole lot of real big vehicles, as American consumers traded their 14-mpg, 5000-lb (2268-kg) **Cadillac Escalades** for 24-mpg, 4000-lb (1814-kg) **Buick Enclaves** or even smaller crossovers," said Schultz, a veteran metallurgist.

In 2004, average U.S. market curb weights peaked at 4018 lb (1823 kg), Schultz noted, with 42% of production being body-on-frame vehicles. The average 2009 U.S. market vehicle weighs 3755 lb (1703 kg), with only 25% of the production mix being full frame. The resulting average weight reduction in recent years: about 260 lb (118 kg). And as the accompanying graph reveals, the decline in vehicle mass is expected to continue through 2020.

"In the next decade, we won't see the average unibody vehicle getting too much smaller—the U.S. will pretty

much continue to be a C- and D-segment market although some makers will bring in A- and B-class cars for specific regions," Schultz explained.

North America, it should be noted, offers the most opportunity for significant mass reductions due to its traditional large-vehicle fleet mix.

Given those assumptions, it will be up to designers, engineers, and materials experts to further reduce average vehicle mass to the 3500-lb (1588-kg) average forecast for the 2020 North American fleet by Ducker Worldwide. That is a drop of about 255 lb (116 kg) from the '09 average.

Aluminum's success

For automakers, the path to vehicle mass reduction requires a systems strategy, say experts.

"It's a delicate balance matching the overall vehicle weight against improved powertrain efficiencies, the body, and the interior," said Matthew Zaluzec, Ford's Manager of Materials Research.

The lightweighting technologies currently in Ford's labs will apply to vehicles from 2012-25, he said. "We're not inventing new materials, but rather applying the right materials that are cost competitive," Zaluzec explained.

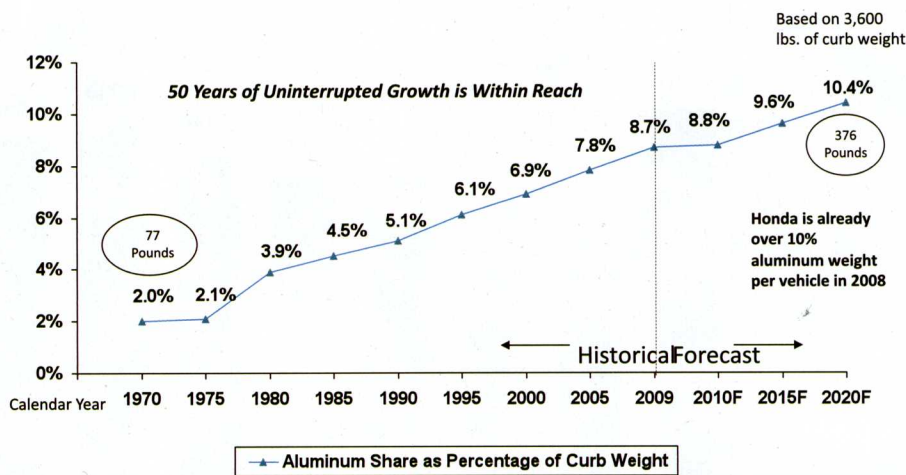
The system and materials mix Ford has adopted for its vehicle mass-reduction plan centers on using increasing percentages of advanced high-strength steels (AHSS) for the body-in-white. Aluminum and magnesium will be used for closures and, depending on the vehicle program, for various structural and chassis applications such as magnesium radiator supports and suspension systems. The mixed-material strategy is fundamentally similar to those of other major OEMs.

"Lightweighting is never for free," Zaluzec asserted. "We've done aluminum-intensive vehicles, including the current **Jaguar XJ8** and the **Ford GT** super car. There's a major up-front investment in manufacturing process," he said. There is also an ongoing debate about value proposition.

On the merits of its curb weight alone, the XJ8 appears to make a strong case for going the all-aluminum route. The 2009 base model, its body-in-white a matrix of 5000-series-alloy stampings, castings, and extrusions, and 6000-series alloy exterior panels, tips the scales at 3770 lb (1710 kg). That's 580 lb (263 kg) lighter than the base **Lexus LS460**, a predominantly steel-bodied competitor with comparable powertrain specifications. It is also the lightest sedan in its segment.

However, the Jag's 16/25 mpg **U.S. EPA** fuel economy rating is essentially identical to the **Lexus' 16/24 mpg**. In an era where even a luxury vehicle's CO₂ footprint increasingly ranks near the top of purchase considerations, a costly and complex rivet-bonded aluminum body shell might present a challenging business case.

Not if you are **Audi**, however. As the industry's volume leader in aluminum-



Aluminum's value as a mass-fighter will continue to grow through more closure-panel applications, including doors, and a continued conquest of chassis and powertrain components.

structure vehicles since the breakthrough A8 in the 1980s, Audi has pushed ahead with its lightweight spaceframe technology, now used on the **TT**, **TT Roadster**, **A8**, **R8**, and **Lamborghini Gallardo**.

The latest ASF (Audi Space Frame) architecture introduced on the 2008 **TT** models is an aluminum/steel hybrid that cuts weight by around 100 kg (220 lb) compared to the previous all-steel structure. The company estimates the reduced weight will decrease fuel consumption by 0.7 mpg.

The construction features aluminum extrusions and castings, with a mix of sheet-aluminum and steel exterior panels and closures, and steel structural elements. The frame sections vary in type, size, and thickness depending on load, and although the side sills on the **TT Coupe** and **Roadster** are visually similar aluminum extrusions, the **Roadster's** sill features thicker internal ribbing to provide the added torsional rigidity needed by the open-top car.

There is also a steel bulkhead behind the **Roadster's** seats that joins the steel subframe that extends from the B-pillar to the rear of the car. The **TT Coupe** and **Roadster** both use steel doors with extruded-aluminum side-impact beams. The **Roadster** also employs a steel decklid while the **Coupe** uses aluminum. The remaining Class-A exterior panels are stamped aluminum sheet.

The **Coupe** body shell weighs 455 lb

(206 kg), of which 309 lb (140 kg) is aluminum—68% of the total by weight. High-strength steel makes up the remaining 32%. Audi engineers claim static torsional rigidity is increased 66% compared with the previous structure. The steel content in the rear of the cars is also used to balance weight distribution, for improved handling.

To join the dissimilar metals, Audi continues to invest in the sophisticated, costly tools and processes to make it happen in volume. The processes include punch riveting and adhesive bonding, which eliminates galvanic corrosion.

Audi is readying the next-generation mixed-metals body architecture for its MY2011 A6 platform. Dubbed ASF-II, it will offer a claimed 50% reduction in body shell weight and 50% greater structural rigidity compared with the current A6. Further use of steel reinforcements with new joining processes are expected.

The company is committed to applying ASF-II up and down the product portfolio to increase manufacturing scale and thus lower investment costs. Lessons learned on the high-cost A2 program will be useful in driving the technology down market into the A3 and even smaller future models. And ASF-II applied to the large Q7 crossover SUV potentially could save up to 660 lb (300 kg).

The use of aluminum sheet for clo-

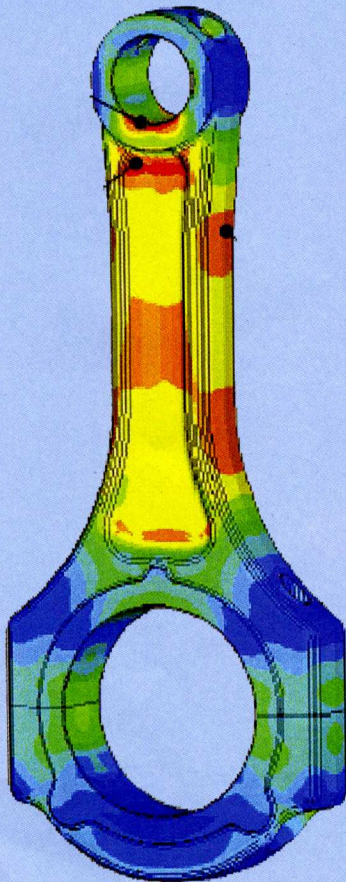
Investigating aluminum con rods

The push for greater vehicle efficiency has advanced materials researchers exploring light-metals applications in various powertrain reciprocating components. Forged aluminum connecting rods were used successfully for 50 years in mass-produced British motorcycle engines and are popular in drag-racing circles. Today they are under development at **Peak**, the supplier of aluminum cylinder liners for **Honda** V6 engines.

According to Peak North America President Bill McCall, con rods forged in Peak's proprietary Dispal S232 alloy offer a 1-lb (0.5-kg) mass reduction per unit—6 lb (3 kg) total in a six-cylinder engine—compared to conventional powder-metal steel con rods. Concerns regarding aluminum's fatigue limit in this high-stress application are addressed in the component geometries and the Dispal material properties.

McCall noted that techniques for precision-fracturing (cracking) the big end are being investigated. Peak prototyped aluminum con rods for Honda's recently canceled V8 engine program.

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sure panels continues to grow.

According to **The Aluminum Association**, the number of closure programs globally has risen from 231 in 2006 to 263 programs in 2009, a 14% gain. Hoods and decklids offer a 40 to 50% weight savings over the comparable steel part—and being large panels they are logical targets for cutting weight.

In 2009, a record 22.3% of vehicle production will have an aluminum hood. "Every year, aluminum gains about one market-share point in hoods," noted Schultz. "We think that application will be 35% by 2020."

"Approximately half of Ford vehicles already have aluminum hoods and more are on the way," commented Zaluzec. "Now we're doing R&D on aluminum doors—a traditional steel application," he revealed. "I won't say when we're going to put them into production, but they're part of our overall weight-reduction strategy."

As a percentage of average vehicle curb weight, aluminum reaches an all-time high at 8.7% in 2009—about 326 lb (148 kg) of all product forms per North American light vehicle. Steady growth is expected in suspension and driveline components, along with a final assault on the remaining 25% of engine cylinder blocks still in cast iron. Experts expect aluminum's percentage of average curb weight to exceed 10% in 2020.

"Powertrain improvements alone will not be enough to get automakers to the necessary fuel economy improvements that are going to be expected," said Buddy Stemple, Chairman of The Aluminum Association's Auto and Light Truck Group. "With the current state of the industry, aluminum will be significant in key automotive decisions concerning fuel economy and mass reduction overall."

To Stemple's point, **Toyota** will launch the first production aluminum-based wiring harness, on its MY2011 Yaris subcompact. The harness, to be supplied by **Sumitomo Electric Industries**, will be nearly 40% lighter than conventional copper wire and is expected to be less expensive. That is a potential boon to B-segment and smaller vehicles that inherently are not laden with excess mass. However, it comes with a compromise—the aluminum harness also will be up to 25% larger in diameter than a copper-based harness.

AHSS hits prime time

Charging fast and furiously into the body structure arena are AHSS, including martensitic, boron, and dual-phase materials. And they get materials gurus like Ford's Zaluzec plenty excited over their potential.

"We're talking 500 MPa and above in tensile strength for some of them," Zaluzec exclaimed. "AHSS allows us to take up to 15% of the weight out of a steel body structure while optimizing the overall body architectures and really improving the strength-to-weight ratio of crash-critical areas such as rockers, sills, pillars, crossmembers, and bulkheads."

The 2009 **Acura MDX/Honda Pilot, BMW X6**, the GM Lambda crossovers (**Chevrolet** Traverse/**Buick** Enclave/**GMC** Acadia/**Saturn** Outlook), **Honda Civic**, and **Nissan Altima** all use a high proportion of AHSS in their bodies-in-white.

In a study due to be presented next month at the **American Iron and Steel Institute** (AISI)'s "Great Designs in Steel" meeting, Ducker Worldwide's Dick Schultz forecasts 250 lb (113 kg) of AHSS and 20 lb (9 kg) of aluminum will replace 346 lb (157 kg) of mild steel and various bake-hardenable and high-strength steels for upcoming body, bumper and closure applications.

"In the last two years, AHSS use has grown at 16.5% per year," he reported. "While some of that growth is due to the recent shift to unibody, as those vehicles generally use more advanced steels than do body-on-frame vehicles—although the new F-150 uses quite a bit and the **Dodge** Ram uses some—we expect that growth to continue at around 10% per year."

The AHSS grades are more expensive than conventional high-strength types, and their value relative to aluminum is determined by formability, Schultz explained. It also depends on part geometry. Some of the black-metal parts are complex and very difficult to form, he said. Steel makers are seeing a shift to martensitic and boron bumper beams because the auto industry is learning how to engineer and produce these parts in AHSS.

"They have to hot-stamp the boron and roll-form the martensite," Schultz noted. "And they're starting to compete

quite favorably with aluminum from the standpoint of cost and weight savings. A- and B-pillars, door beams, those kind of parts which essentially look like aluminum extrusions. Their geometries tend to work well with those advanced steels."

AHSS generally are not expected to be a major candidate for closures or large body parts in the future, the experts reckon. Even the 980-grade dual-phase steels do not offer the mass savings of aluminum for closure applications.

"The fundamental rule is even these advanced steels are going to cost less than the equivalent aluminum part—but only in rare exceptions can they save as much weight. So engineers balance it all out," Schultz observed.

The most AHSS-intensive vehicle for MY2009 in terms of body content is BMW's X6. The D-segment crossover uses 32% AHSS in its body-in-white and closures, according to the Ducker Worldwide study. The Altima is also at 32% AHSS, but the larger X6 contains more pounds of the steels.

Lincoln's 2010 MKT large crossover body structure contains about 16% AHSS. It is one of Ford's leading vehicles in terms of lightweight materials content and the company's highest in North America.

"The 16% doesn't seem like much compared with the X6's 32%, but Ford's made a lot of progress in a very short time," Schultz opined. The F-150 also contains 16% AHSS, high content for a body-on-frame vehicle.

"We consider BMW and Honda to be the 'poster children' for production application of advanced high-strength materials," Schultz said. "Both companies use the most amount of AHSS and aluminum per vehicle." He reasoned that the two automakers cannot be labeled as being in any one materials camp.

"If you're pushing the materials-technology envelope, you're using aluminum; you're using high-strength martensitic, boron, or dual-phase steels; and you're using magnesium. In my view, BMW and Honda are probably 10 years ahead of some of the other OEMs in this area," he noted.

Honda's 2010 Insight hybrid sedan is larger and weighs more than its aluminum-intensive predecessor introduced in 1999. The company opted for a variety of AHSS and HSS grades to meet body structure, occupant safety, and

The plastic and carbon-fiber composite roof panel of the new BMW M3 cuts weight and lowers the center of gravity when compared to a conventional steel roof. Carbon fiber costs and volume demands by the aerospace industry ensure the strong, lightweight composite will remain a niche material for premium vehicle applications in the near to mid-term.



cost targets. A main bogey was to keep development costs down so the Insight would be one of the most affordable hybrids on the market.

"We're using high-strength steel more than any other tool in our holster," a company insider told AEI.

Ron Krupitzer, Vice President of Automotive Applications at AISI, commented that "Honda is more value-oriented, and on a mass-vs.-power rating, Honda is good. It comes down to priorities, and Honda has stuck to steel."

Keeping hybrid and electric vehicle (EV) curb weight to a reasonable level is a delicate balance, engineers note. The added weight of the electric drivetrain and batteries means both vehicle mass and cost are critical. It is worth noting that Toyota's new-generation Prius, and the Chevrolet Volt being readied for late 2010 production, use primarily steel body structures. Niche and premium-market entries, such as Tesla's EV roadster and Fisker Automotive's plug-in hybrid sports sedan, are engineered with relatively high aluminum content.

To meet the anticipated growing demand for AHSS, the steel industry is working on adding manufacturing capacity. But the key to optimizing the excellent characteristics of AHSS (and unlocking more vehicle applications) is learning how to use them.

"We don't need many more new steels," noted Zaluzec. "What we need instead are further engineering work in forming and joining, and recovery on the current parts." He and other experts note AHSS has different springback characteristics, making it a challenge to form complex geometries consistently.

Schultz echoed Zaluzec: "What the auto industry needs is to perfect ways

to weld the dual-phase, and to form the martensite and the boron, and predict the tooling so we don't have to have die tryouts for two months on every part," he said.

As an example, Benteler and Magna learned how to make boron beams without excessive scrap using the hot stamping process. This has sparked huge interest in boron beam applications at the OEMs. Volkswagen has switched 100% of its bumper beams to boron AHSS.

"The [beams] resemble toothpicks compared with the old beams they're replacing," Schultz noted. "They only weigh 7 or 8 lb; they have 1400 MPa tensile strength. Fantastic. The suppliers' mastering of the hot-forming process made a big difference," he said. (As a counterpoint, Honda recently switched its Civic bumper beams to aluminum.)

In their drive to optimize vehicle mass and structural integrity, engineers are using bio-mimetic topology modeling tools in their body development activities. These tools help identify which body-in-white zones have the highest strain and help determine critical-load paths on the vehicle.

Chrysler's Knowledge-Based Engineering group, in collaboration with MBtech, Mercedes' Research Group, and AISI, created a proprietary process with the so-called "bionic" tools that allows engineers to accelerate the use of AHSS in new bodies-in-white.

"It allows you to peel away weight where you don't need it," Bill Grabowski, Director of Body Core Engineering, told AEI. He predicts as much as 120 lb (54 kg) could be shed from the body-in-white through bio-mimetic topology.

Shuffling the DECS with a lightweight seat

Seating giant **Lear** is readying a new seating system for 2010 production that will offer significantly lower mass per seat set, as well as greater comfort and lower environmental impact. This illustration is the first public view of the Dynamic Environmental Comfort Seat, known as DECS.

According to Ash Galbreath, Director of Advanced Materials, DECS' radical design features a three-layer sandwich of various foam materials to perform structural, comfort, and tactile tasks. The bottom layer attached to the lightweight hydroformed seat frame is molded in semi-structural expanded polypropylene (EPP) foam. EPP can be produced in a range of hardnesses, allowing Lear to replace the traditional stamped steel anti-submarining pan, heavy wire mesh, and various metal brackets and clips.

DECS' middle layer is in Lear's soy-oil-enhanced BioFoam; it provides occupant comfort and support in combination with the top layer of polyester foam. DECS' multi-material construction is fully recyclable, and its foam structure weighs approximately half that of conventional seat-cushion sets.

Competitors **JCI**, **Magna**, and **Faurecia** also are developing lightweight seating solutions.

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Chrysler vehicles currently employ approximately 20-30% HSS. Grabowski indicated that total will rise to 60% by 2012, with AHSS content of up to 30% in body shells expected to arrive by 2010.

New apps for magnesium, plastics

The liftgate inner panel in Lincoln's 2010 MKT crossover, along with the front radiator apertures in the MKT and '09 F-150, signal Ford's intention to increase its deployment of magnesium alloys across its vehicle lines moving forward. Other makers are following similar paths. With high specific strength and the lowest density among all structural alloys, magnesium offers big potential in structural applications where systems mass reduction is critical. And magnesium's traditional price premium is being offset by stringent fuel-efficiency standards in many global regions.

On the MKT, the cast-magnesium liftgate inner panel is combined with an aluminum outer. The mag part was specified to help keep the primarily steel-bodied vehicle within its weight-class target. According to MKT Chief Engineer Ron Heiser, it saves more than 20 lb (9 kg) compared with a stamped steel panel. It is supplied by **Meridian Magnesium Products** and is

claimed to be one of the largest single magnesium parts currently in automotive production.

Meridian also supplies GM with the industry-first magnesium front cradle introduced on the 2007 Corvette. Die cast in AE44 alloy, it provides a 35% mass savings over the previous aluminum cradle. GM engineering management is pleased with the results and is currently conducting a demonstration program for magnesium use in other load-bearing areas.

A major driver for the increased use of magnesium alloys in automotive applications has been refinements in alloy processing and composition, with new approaches to component design. A newcomer attracting the auto industry's attention is **T-Mag Casting Technology**. The Adelaide, Australia-based company is demonstrating a patented permanent-mold magnesium casting machine that integrates melting and casting operations into a single manufacturing cell.

According to Fred Nader, Director of U.S. Operations for **Team Australia Automotive**, representing T-Mag, the process is capable of handling small to medium sized components in complex geometries including sports-type road wheels and engine cylinder blocks. Cycle times are faster than using comparable aluminum gravity-cast permanent mold processes, Nader said. "And the equip-

ment produces to near-net shape for minimized machining—there's less than 5% process scrap," he noted.

T-Mag is collaborating in the United States Council for Automotive Research (USCAR) High Integrity Magnesium Automotive Castings (HIMAC) research project to develop new permanent-mold process technologies using a lower control arm as its initial proof-of-concept part.

While it may appear that most of the major gains in lightweighting are expected to come from the metals industry, that is clearly not the case. Plastics and composites suppliers have turned up their R&D, and the results of their efforts are omnipresent in 2009-10 vehicles. The average vehicle contains more than 330 lb (150 kg) of plastic, and each pound of it supplants 2-3 lb (up to 1.4 kg) of primarily metals.

[For a recent review of innovative, mass-reducing plastics engineering on new vehicle components and systems, please see "Prize-winning plastics," December 2008 *AEI*, p.22.]

Another area receiving much focus is new solutions for NVH attenuation within the vehicle structure. Jim Federico, Global Vehicle Line Executive for GM's midsize cars, notes the new lightweight acoustic damping mats being deployed across GM's global product portfolio. The mats, known as liquid-applied sound deadener (LASD), were pioneered on the T900 truck program.

"The savings is in multiple pounds per vehicle," Federico told *AEI*. "We're currently migrating this technology to floorpans and bulkheads" of GM's new Global Epsilon, Lambda, and Theta-based products, with future applications to come, he said.

From an overall vehicle standpoint, the addition of 300 lb (136 kg) of advanced and ultra high-strength flat rolled steels, and 50 lb (23 kg) of aluminum in all product forms—plus increased use of structural plastics and magnesium—will be needed to help the OEMs drive curb weight down another 250 lb (113 kg) by 2020.

"It's imperative that materials suppliers stay the course in terms of promoting and technically supporting material substitution during these difficult times for the OEMs and their suppliers," Schultz of Ducker Worldwide intoned. "If the effort is not sustained, the goals outlined above will not be achieved." **aei**